Fibre Optic Communications - Networking

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Module: Fibre Optic Communications

MSc/MEng – Digital Communication Systems

UNIVERSITY OF SUSSEX
SCHOOL OF ENGINEERING & INFORMATICS

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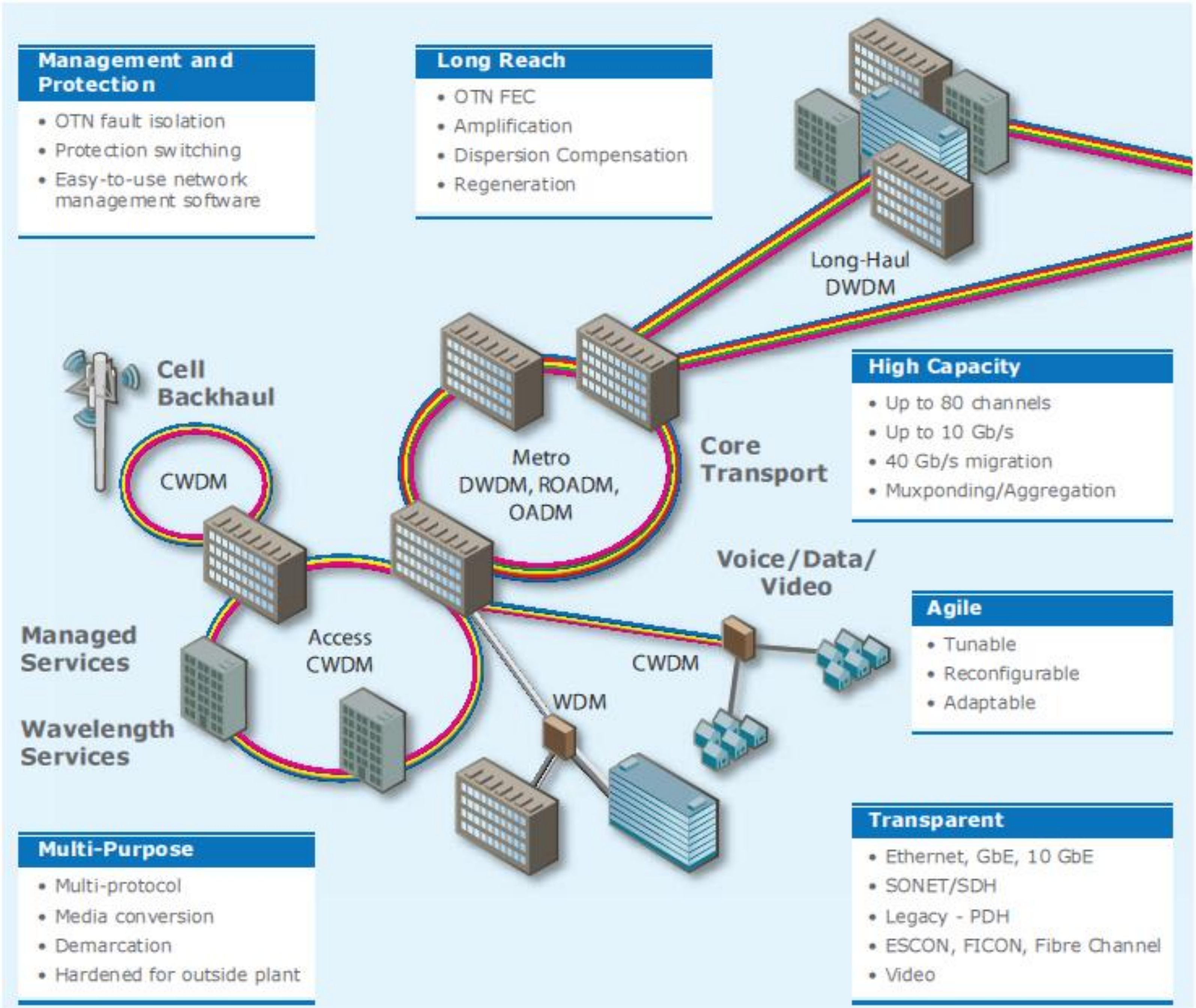
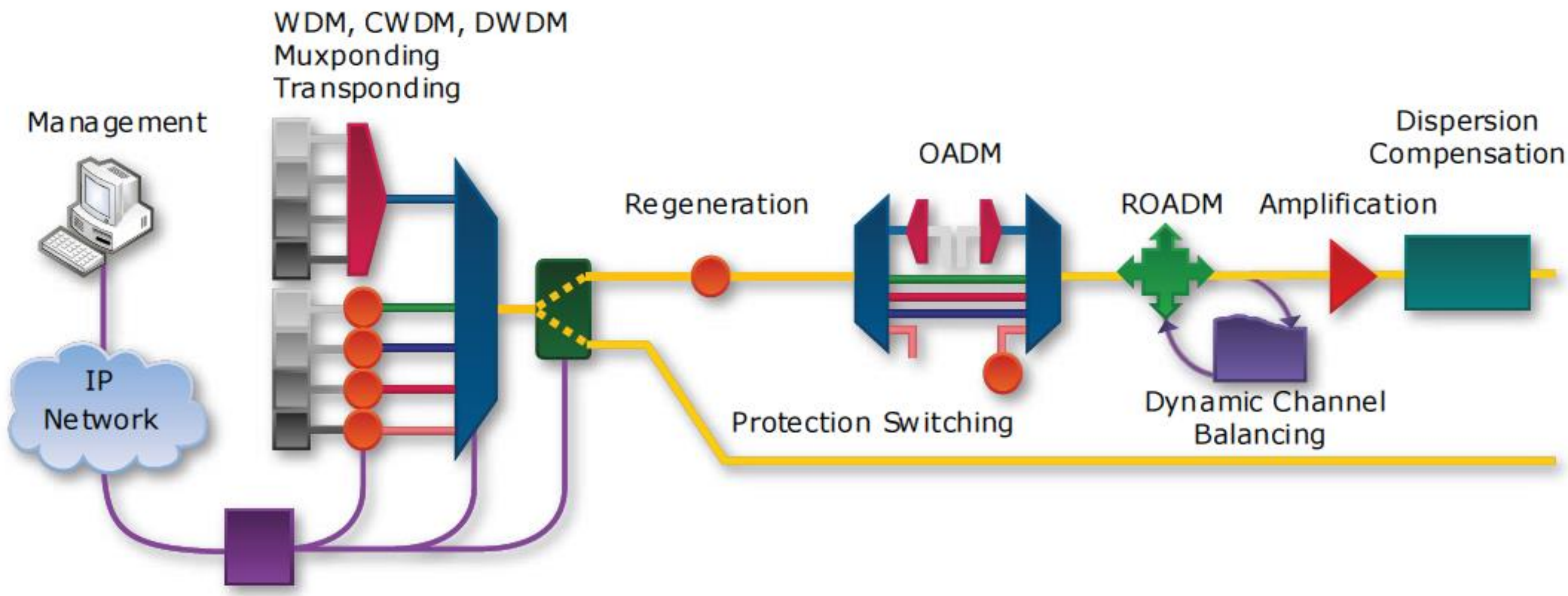
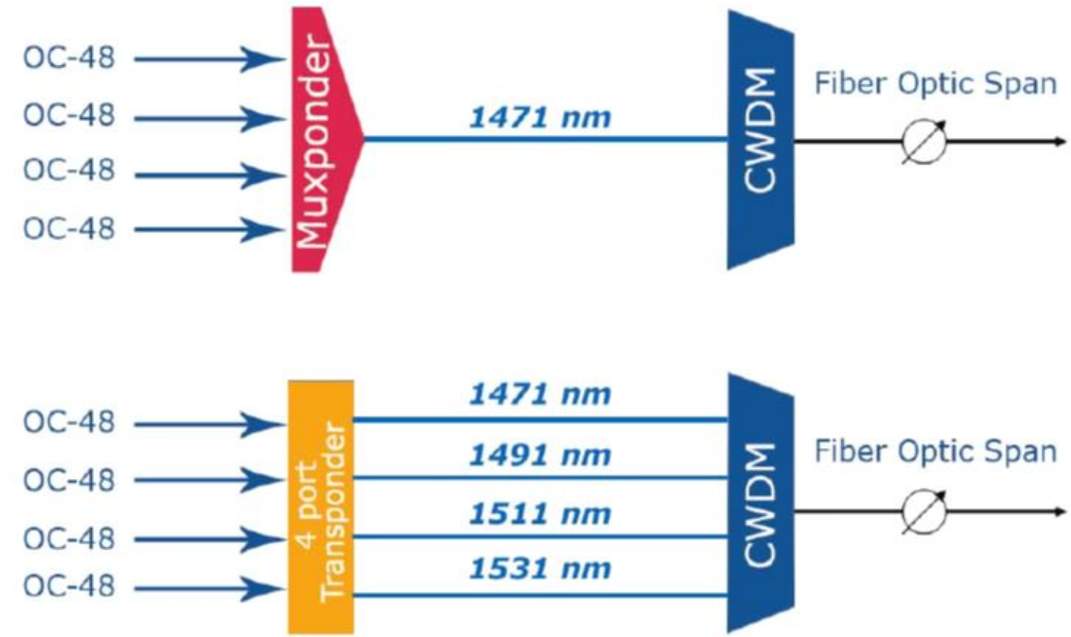

Management and Protection
• OTN fault isolation
• Protection switching
• Easy-to-use network management software
Long Reach
• OTN FEC
• Amplification
• Dispersion Compensation
• Regeneration
Long-Haul DWDM
Cell Backhaul
CWDM
Metro DWDM, ROADM, OADM
Core Transport
High Capacity
• Up to 80 channels
• Up to 10 Gb/s
• 40 Gb/s migration
• Muxponding/Aggregation
Voice/Data/Video
Agile
• Tunable
• Reconfigurable
• Adaptable
Managed Services
Access CWDM
CWDM
WDM
Wavelength Services
Transparent
• Ethernet, GbE, 10 GbE
• SONET/SDH
• Legacy - PDH
• ESCON, FICON, Fibre Channel
• Video
Multi-Purpose
• Multi-protocol
• Media conversion
• Demarcation
• Hardened for outside plant



Multi-port transponder cards allows the termination of 4, 8, or 10 client signals on a single card. This provides greater density and associated space savings but still uses the same number of wavelengths in a CWDM or DWDM system.

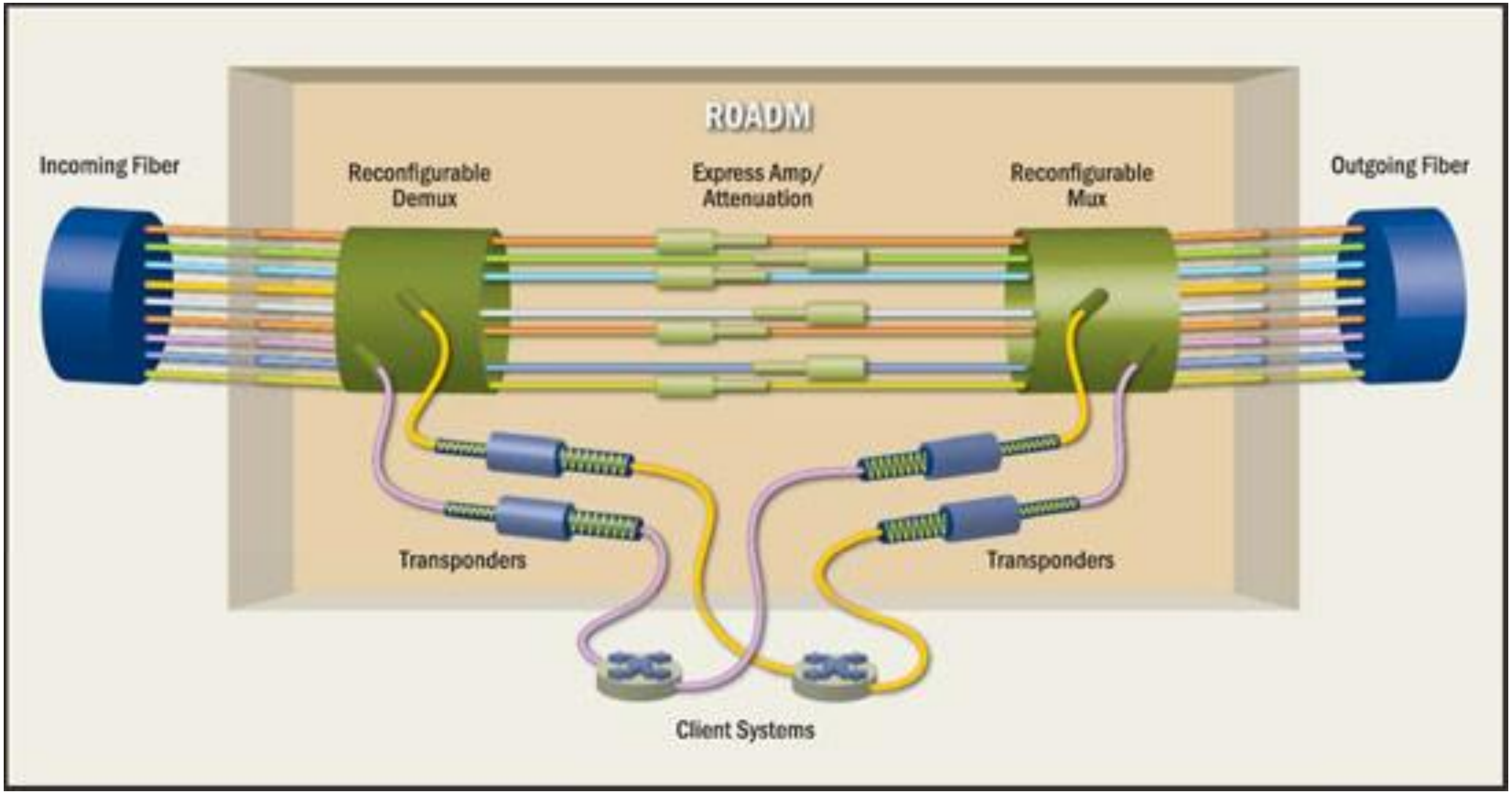
The muxponder takes this concept of increased density a step further and terminates multiple client signals on the same card but then multiplexes them to a common line-rate which uses a single wavelength or fiber. Facilities are saved as well as space and power.

Figure 1: A comparison of a 4-port transponder and a 4-port OC-48 muxponder



- The trade-off between the multi-port transponder and the muxponder is that the transponder will be able to accommodate different client signals within a range (10 Mb/s to 2.7 Gb/s)
- whereas the client signals on the muxponder will usually be the same rate and format.

Reconfigurable Optical Add/Drop Multiplexer ROADM



Three Generic Stages of Deployment for Optical IP Networks

ASYNCHRONOUS TRANSFER MODE ATM
SYNCHRONUS DIGITAL HIERARCHY SDH
SYNCHRONUS OPTICAL NETWORK SONET

IP		
ATM	IP	
SONET	SONET (thin)	IP
WDM	DWDM	DWDM
Existing & inefficient	Starting up	Future goal

Table 17.1 *SONET/SDH rates*

STS=synchronous transport signal – framed data
STM=synchronous transport mode – framed data

STS	*OC*	*Rate (Mbps)*	*STM*
STS-1	OC-1	51.840	
STS-3	OC-3	155.520	**STM-1**
STS-9	OC-9	466.560	**STM-3**
STS-12	OC-12	622.080	**STM-4**
STS-18	OC-18	933.120	**STM-6**
STS-24	OC-24	1244.160	**STM-8**
STS-36	OC-36	1866.230	**STM-12**
STS-48	OC-48	2488.320	**STM-16**
STS-96	OC-96	4976.640	**STM-32**
STS-192	OC-192	9953.280	**STM-64**

SONET frame

SDH frame

A simple network using SONET equipment

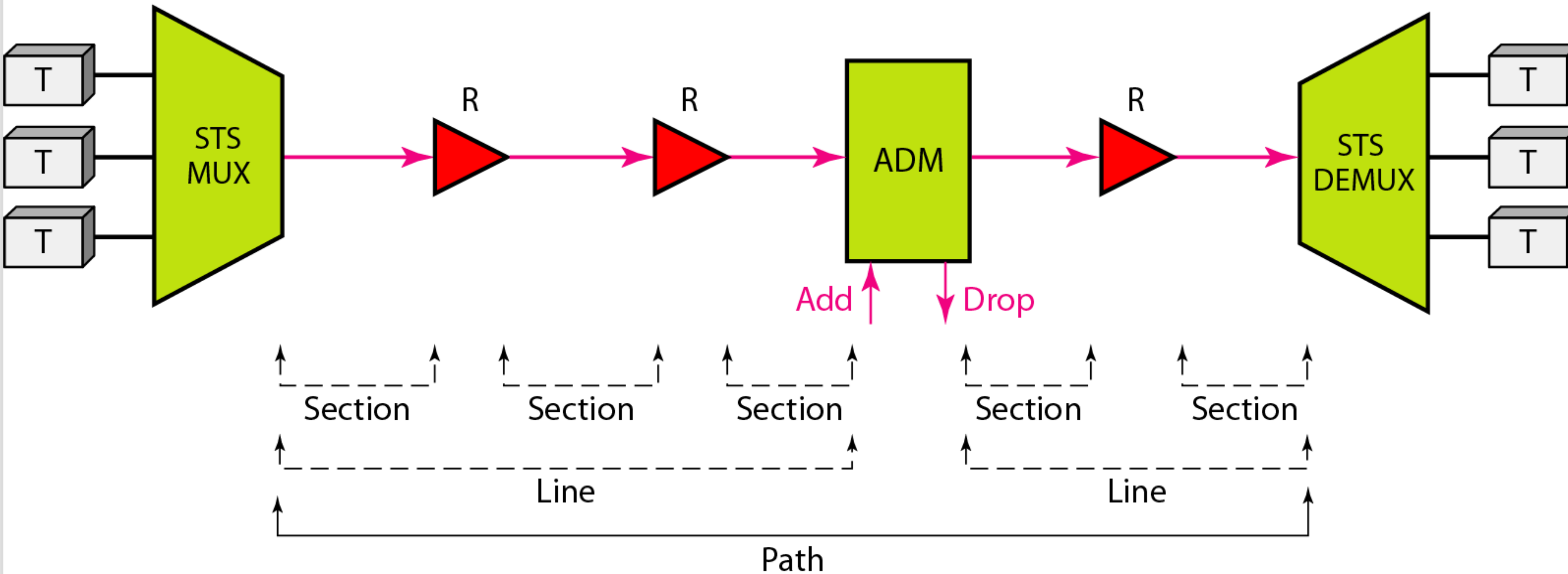
ADM: Add/drop multiplexer

STS MUX: Synchronous transport signal multiplexer

STS DEMUX: Synchronous transport signal demultiplexer

R: Regenerator

T: Terminal

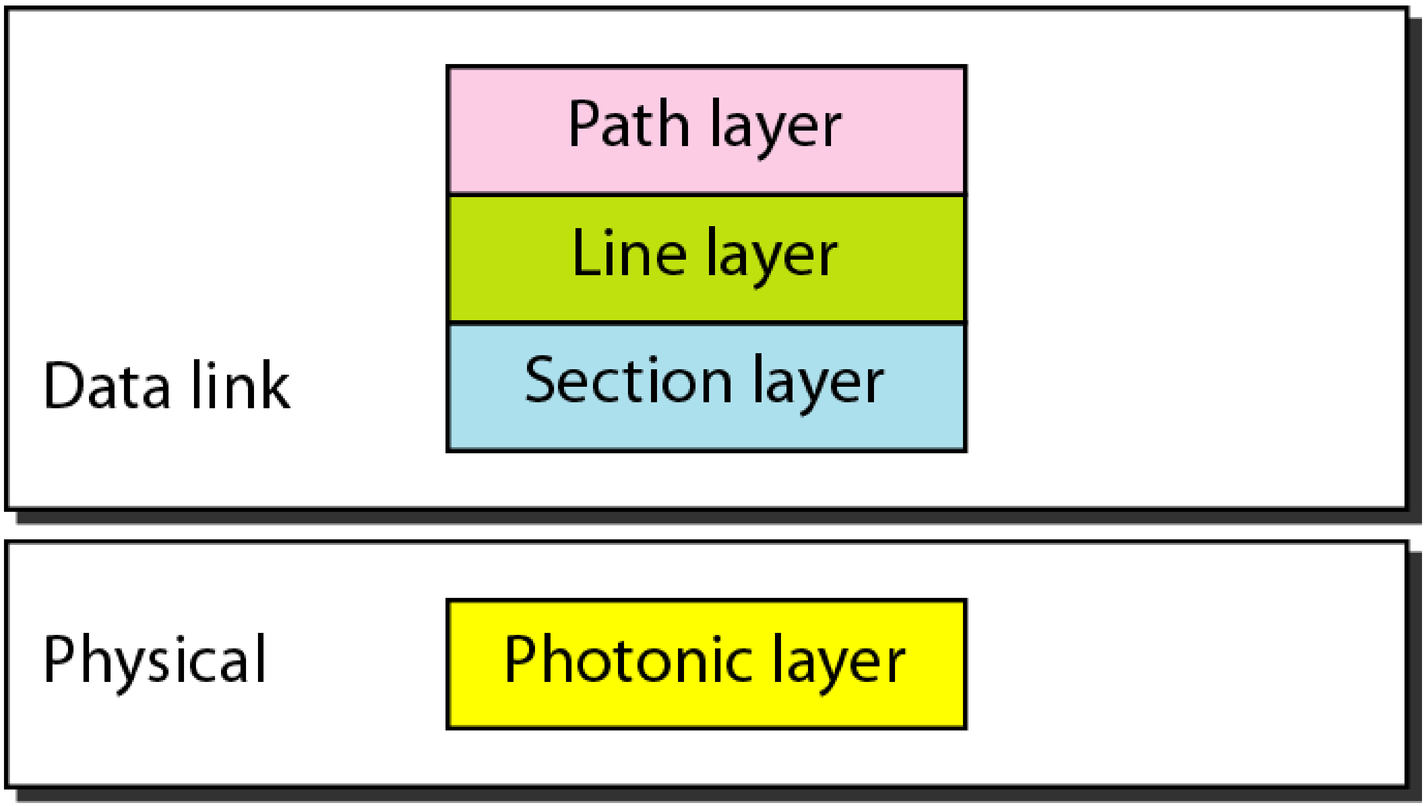


17-2 SONET LAYERS

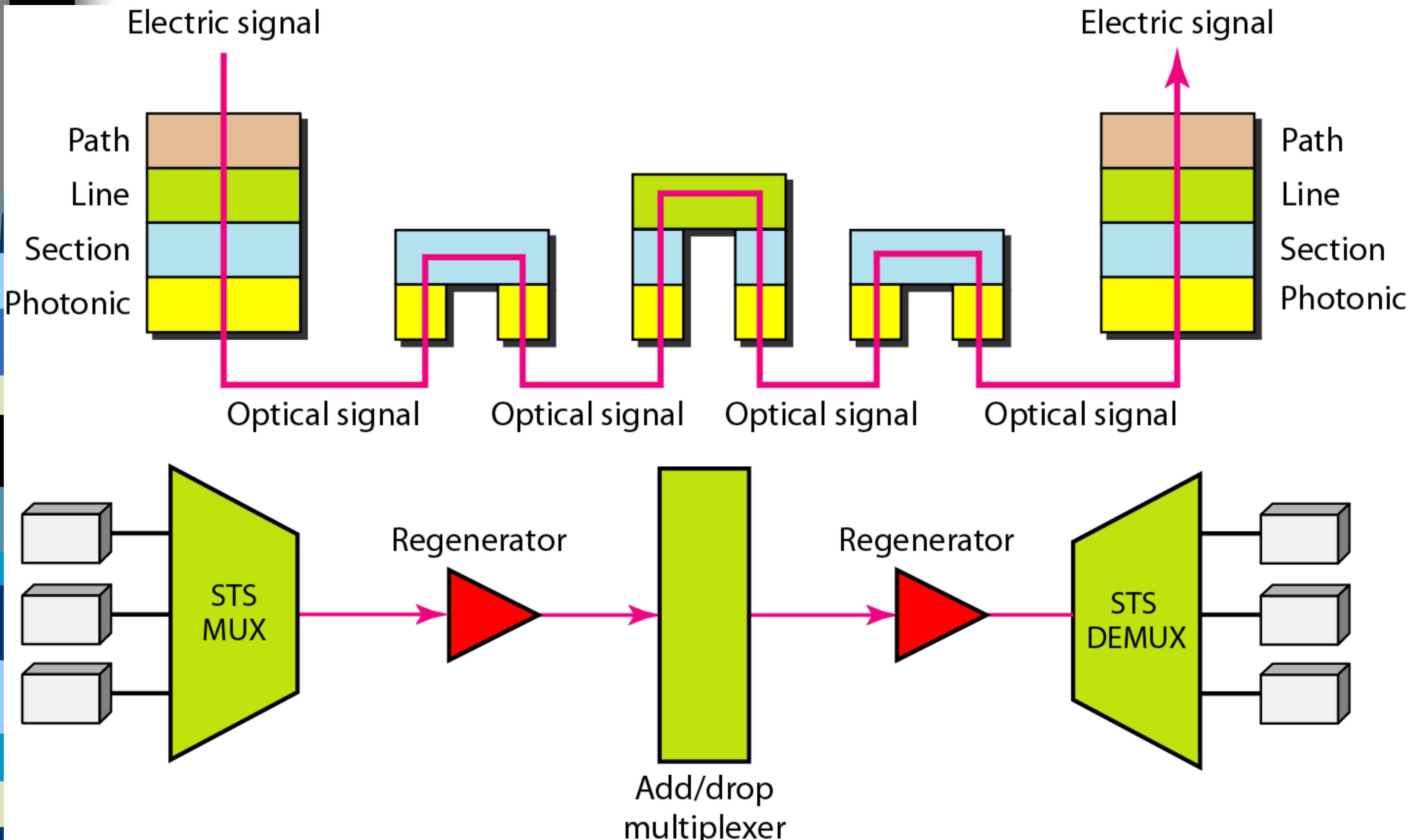
The SONET standard includes four functional layers: the photonic, the section, the line, and the path layer. They correspond to both the physical and the data link layers.

- Path Layer
- Line Layer
- Section Layer
- Photonic Layer

SONET layers compared with OSI or the Internet layers



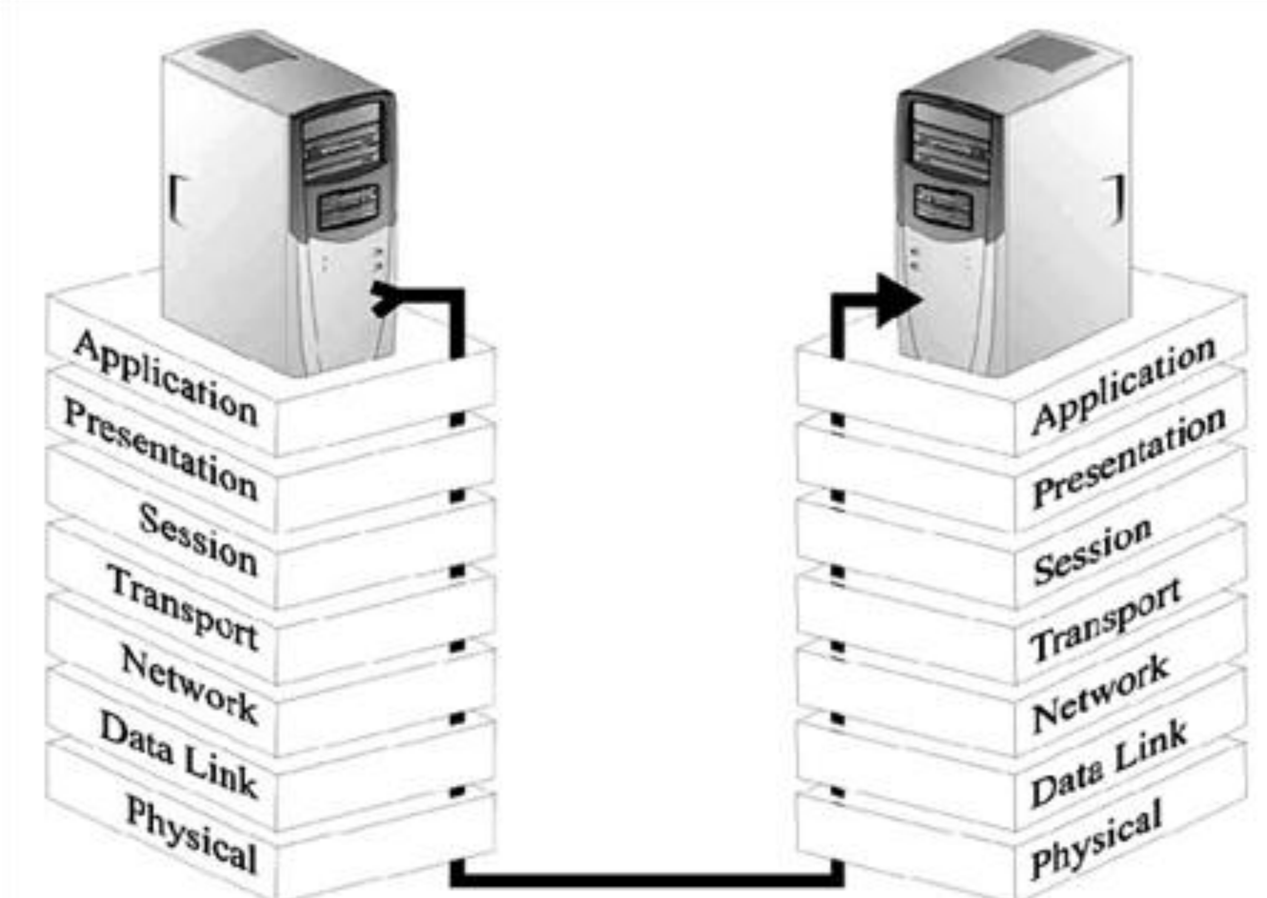
Device–layer relationship in SONET



Open System Interconnect (OSI)

- The **OSI** model is a **7-layer model**, which loosely details how things work.
- *Each* **layer builds** on the **previous** one, **adding functionality** to the capabilities included in the lower layers.

Open System Interconnect (OSI)



OSI Model, showing flow of information from sending PC (left) to receiving PC (right)

Open System Interconnect (OSI)

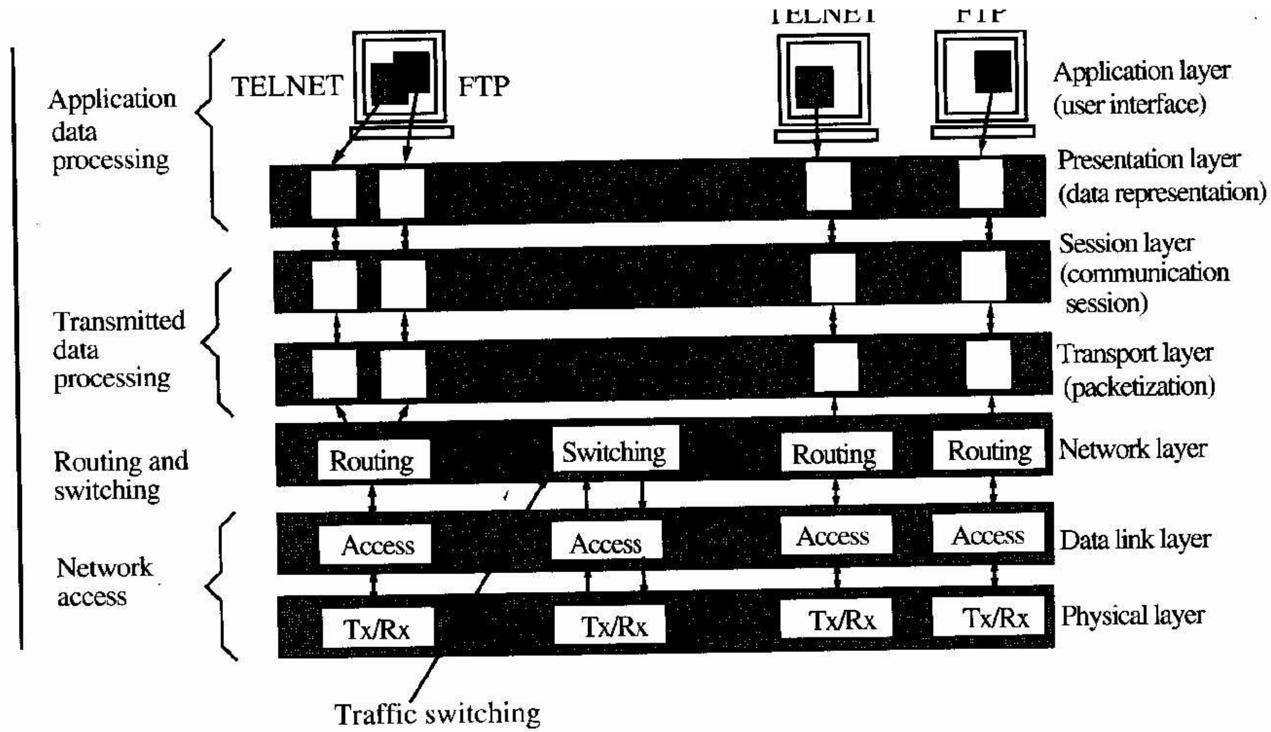
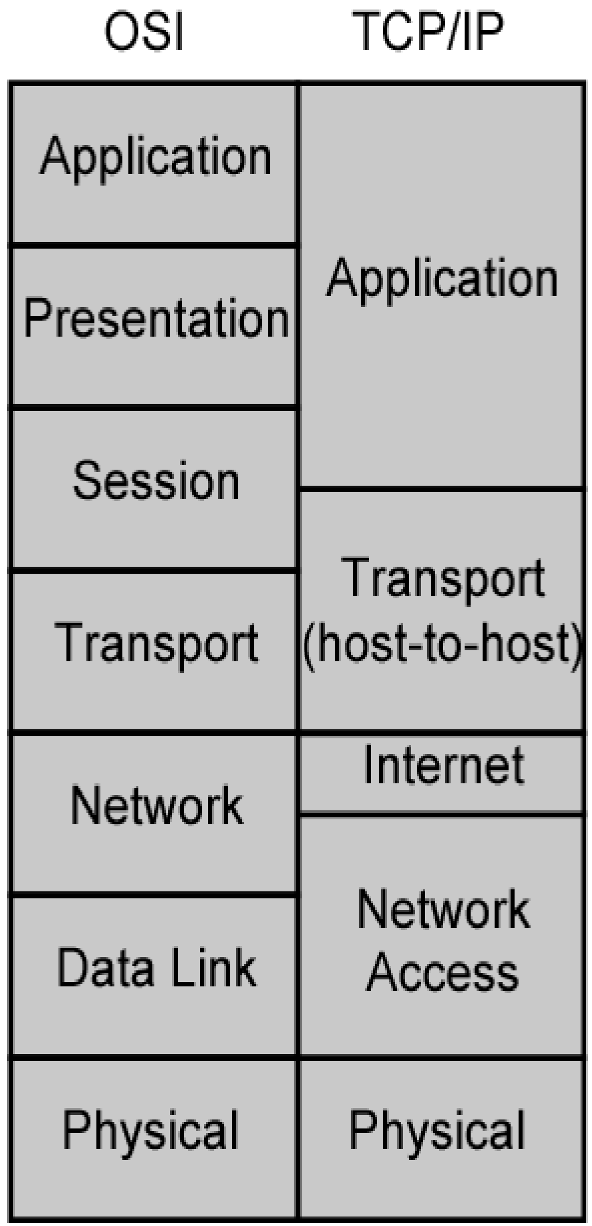


Figure 2.3 The data communication process and the seven OSI protocol layers.

OSI vs TCP/IP


OSI
TCP/IP
Application
Presentation
Session
Transport
Network
Data Link
Physical
Application
Transport
(host-to-host)
Internet
Network
Access
Physical

Importance of the seven OSI Protocol Layers

- By specifying the interface between adjacent protocol layers, implementation of one layer can be made transparent to other layers
- For example, if we want to replace the cable transmission by fibre optics, we only need to modify the physical and data link layers

Medium access control

- Two types of Medium Access Control, figure 2.4:
  - Multiplexing – eg, TDM
  - Multiple access – eg, Ethernet
- Medium-access schemes can be classified according to the form of the shared resource
- Three important forms are: time, frequency and code

Multiplexing and Multiple Access

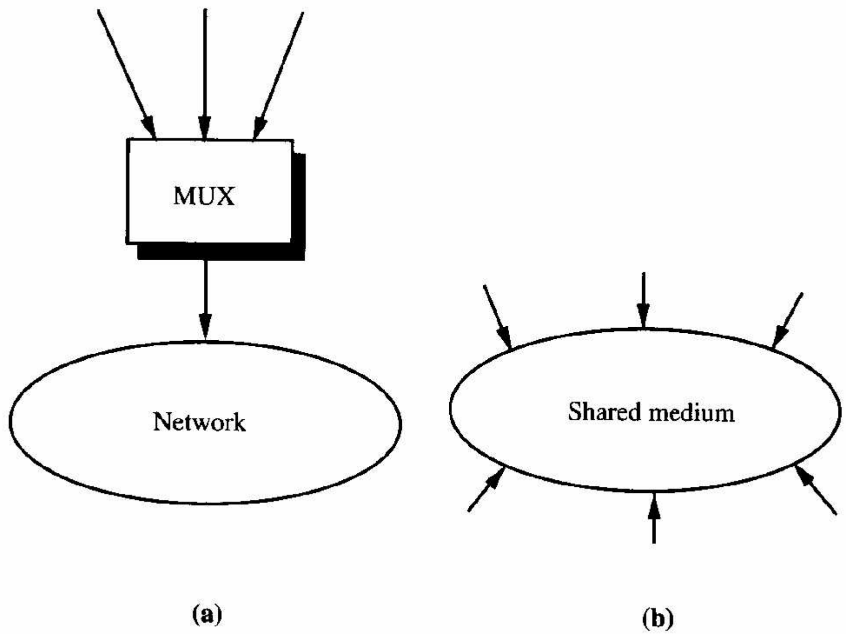
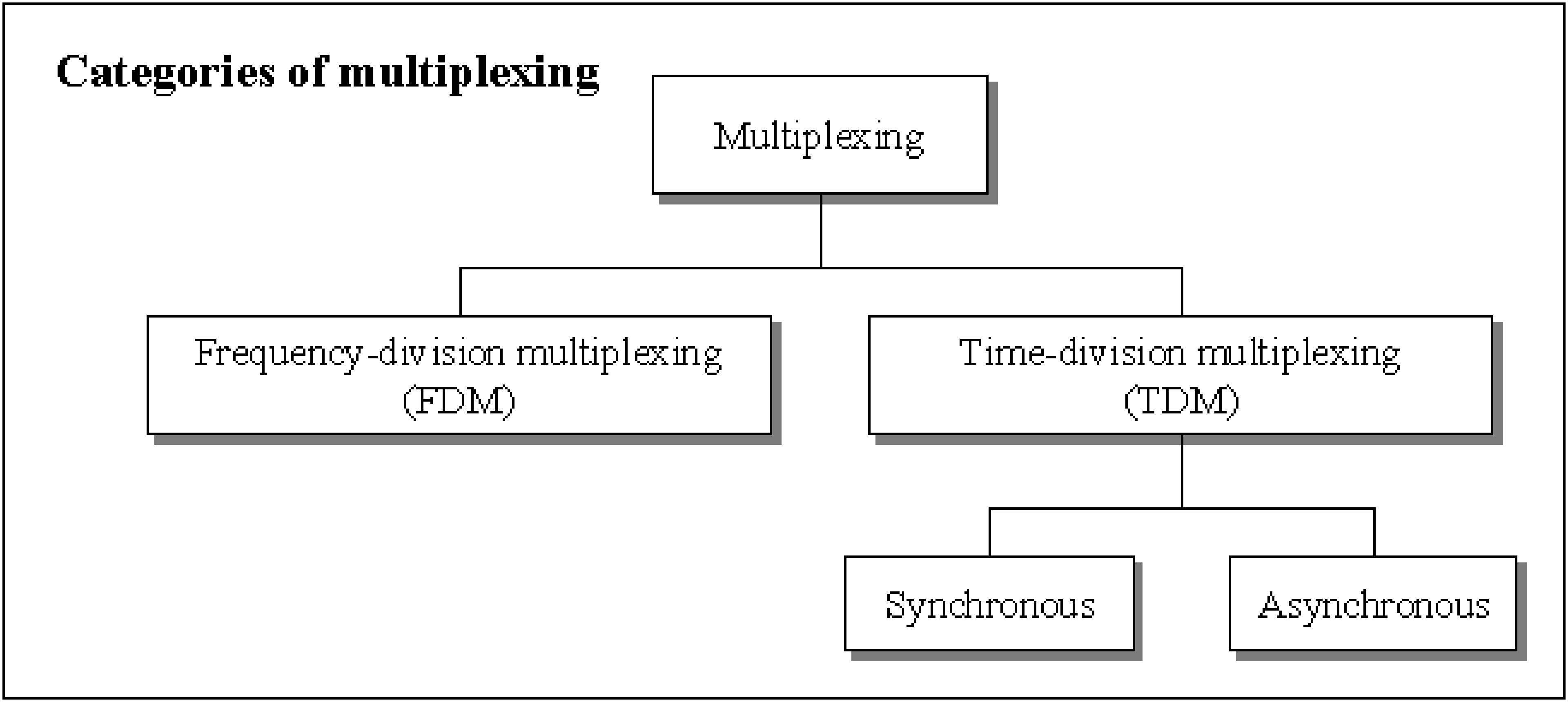


Figure 2.4 (*a*) Multiplexing and (*b*) multiple access.

Type of Multiplexing

- There are two basic techniques:
  - Time-Division Multiplexing (TDM)
  - Frequency-Division Multiplexing (FDM)

- There are two subtypes of TDM: synchronous and asynchronous


Categories of multiplexing
Multiplexing
Frequency-division multiplexing (FDM)
Time-division multiplexing (TDM)
Synchronous
Asynchronous

Wavelength Division Multiplexing

- WDM is theoretically identical to Frequency Division Multiplexing.
- WDM is used in optical systems while FDM is used in electrical systems.
- A method of accessing the shared medium is to transmit signals in different frequency bands
- In optical communications, this is called wavelength-division multiplexing (WDM) and wavelength-division multiple access (WDMA), respectively

Dense Wavelength Division Multiplexing

- Consider 100 channels with channel separation of 10 GHz
- If the first channel is operated at a wavelength of 1500 nm, its corresponding frequency is
- $f_1 = c/\lambda = 2 \times 10^{14}$ Hz
- $\Delta f = 10$ GHz, hence the carrier frequency of the next channel is $f_2 = f_1 + 10^{10} = 2.0001 \times 10^{14}$ Hz
- The corresponding wavelength is $\lambda_2 = 1499.93$nm
- For 100 channels, this means a total spectrum width of 7 nm with a wavelength spacing of 0.07 nm

Dense Wavelength Division Multiplexing

- When transmission is over optical fibres, this is not a problem and WDM can achieve very high throughput
- However, because the output wavelength can vary with temperature or bias current changes, the channel separation $\Delta\lambda$ may be too small
- A typical wavelength shift due to temperature is 0.1 nm/K for single mode lasers
- Compared to the 0.07nm channel separation, we see it is difficult to have a close channel separation in WDM without a good frequency stabilisation scheme

Course Wavelength Division Multipexing (CWDM)

- CWDM systems are medium capacity wavelength division multiplexing systems used over distances up to 80 km (50 miles).
- They are defined by the International Telecommunications Union (ITU) recommendation (standard)
- G.694.2 (2003) as 18 wavelengths spaced 20 nm apart starting at 1271 nm and continuing to 1611 nm.

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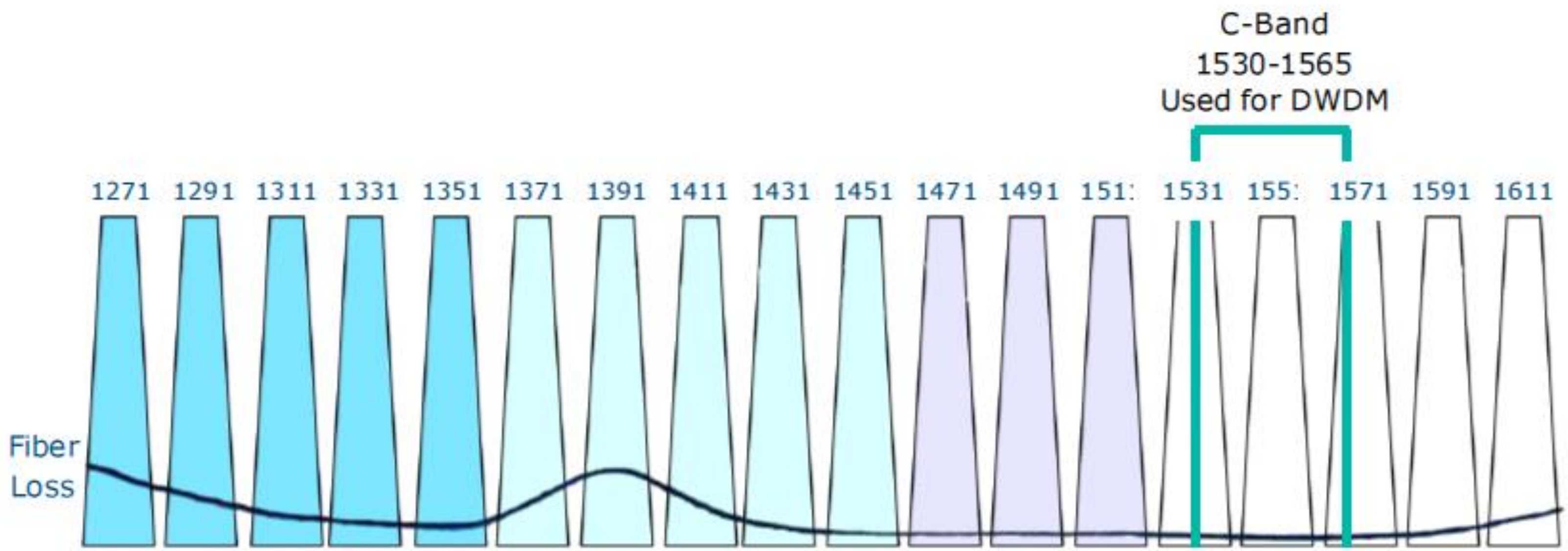


Figure 1 - CWDM Wavelength Grid Specified by ITU-T G.694.2

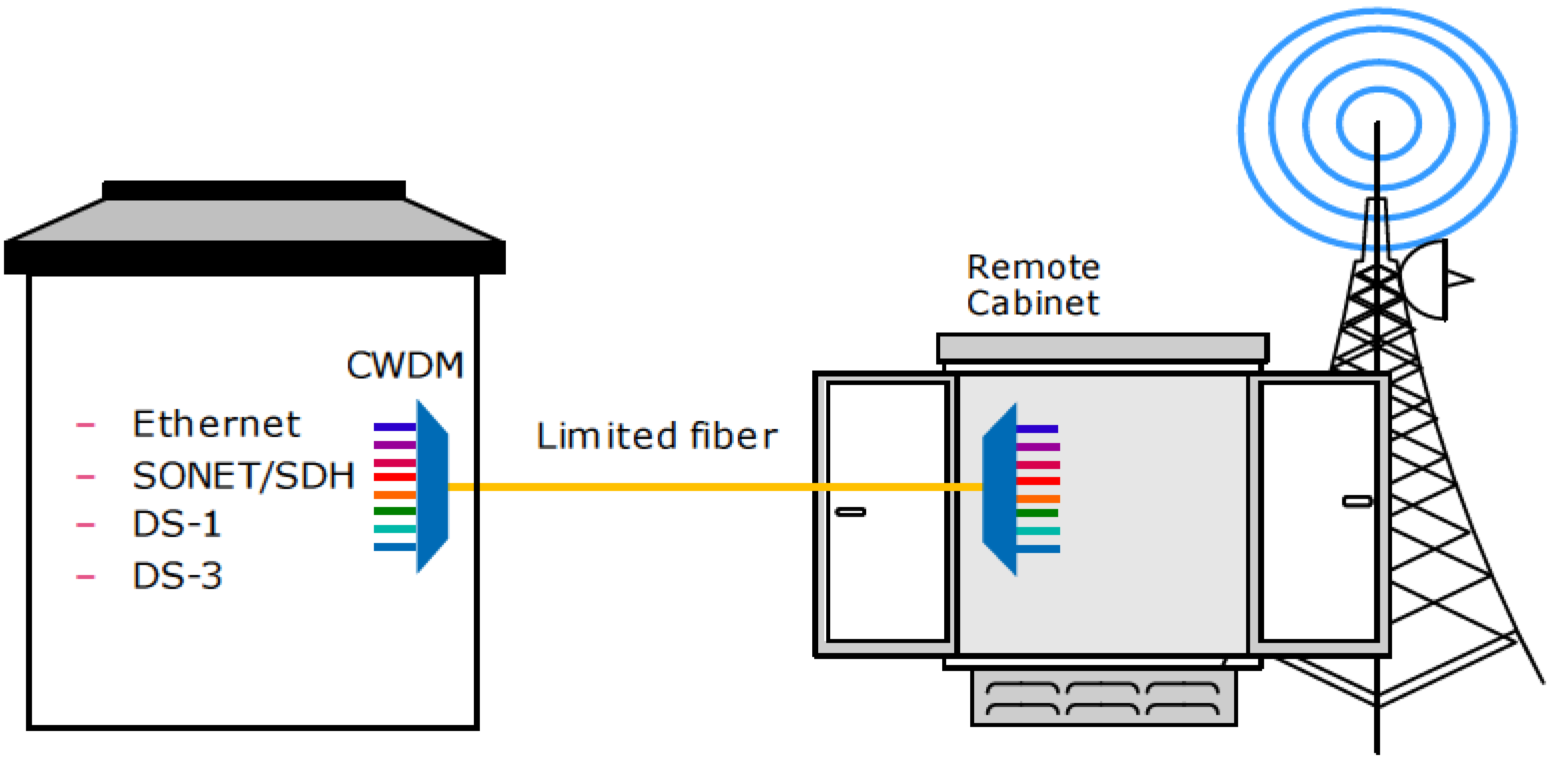
CWDM

- ITU-T G.695 (2009) further defined the technical parameters for 16 wavelength systems carrying data rates up to and including 10 Gb/s.
- Erbium doped fiber amplifiers work only in the C-band (1530 nm to 1565 nm) and are therefore only usable on DWDM systems.
- Since they do not have optical amplification, CWDM systems are typically used in access networks and on shorter, single-span interoffice routes.
- With wavelengths spaced 20 nm apart, CWDM systems do not have as stringent a requirement on frequency drift as DWDM systems.

CWDM - Cellular Backhaul

- A prime application for CWDM is providing capacity for cellular backhaul.
- A cell site will often have three to four cellular providers, each one requiring a dedicated fiber for their backhaul capacity needs.
- A single cellular service provider can require 300 Mb/s to 1 Gb/s, eliminating the ability to use a copper facility.

CWDM - Cellular Backhaul



Multiple access in optical communications

- There are practical systems operating on both the time domain and frequency domain medium accesses
- Time domain medium access is attractive if simple implementation is a primary consideration – stabilisation of the laser output frequency is not required; no need for a tuneable filter or a tuneable laser diode – only a basic optical transceiver is needed for each communication node
- The main disadvantage is the speed bottleneck from modulation and multiplexing

Multiple access in optical communications

- The main advantage of frequency domain medium access is a higher throughput
- By having multiple transmissions at the same time, we can multiply the total transmission bit rate by the number of parallel transmissions
- The main disadvantage is the need for the more advanced wavelength devices

Switching

- Switching is the network function that routes traffic to different destinations
- A basic switch consists of three components:
  - Input/output interface
  - The switching fabric
  - The switching control
- The I/O interface performs the necessary signal format conversion and synchronisation. It then sends input traffic to the switching fabric for routing
- The switching control determines the switching fabric configuration to form desirable connections between input and output ports

Cisco Catalyst 6500 Series Switches

The 9,300 square metre data centre near Frankfurt

- European data centres consumed 56TWh of electricity in 2007 and in the UK they are responsible for almost three per cent of electricity use.

Datacentres

WDM Switch

- A WDM photonic switch using a star coupler is shown in figure 2.10
- A star coupler is a multi-port optical device that couples a certain number of input signals, mixes them uniformly if ideal and distributes them to all the output ports
- In this arrangement an optical filter is used at each output port to select one of the input signals at wavelength λ_i
- In this approach signals are switched according to their wavelengths

WDM Switch

- When we want to increase the switch size, we can just increase the number of wavelength channels
- Because the output filter can select any of the inputs
- This WDM switch has no internal blocking and is logically equivalent to a crossbar switch
- The two main disadvantages of this switch are power loss as the switch size increases and the need for tuneable light sources and filters
- In practice, the size of the switch is limited by how many wavelength channels can be implemented and tuned to

4 x 4 WDM Photonic Switch

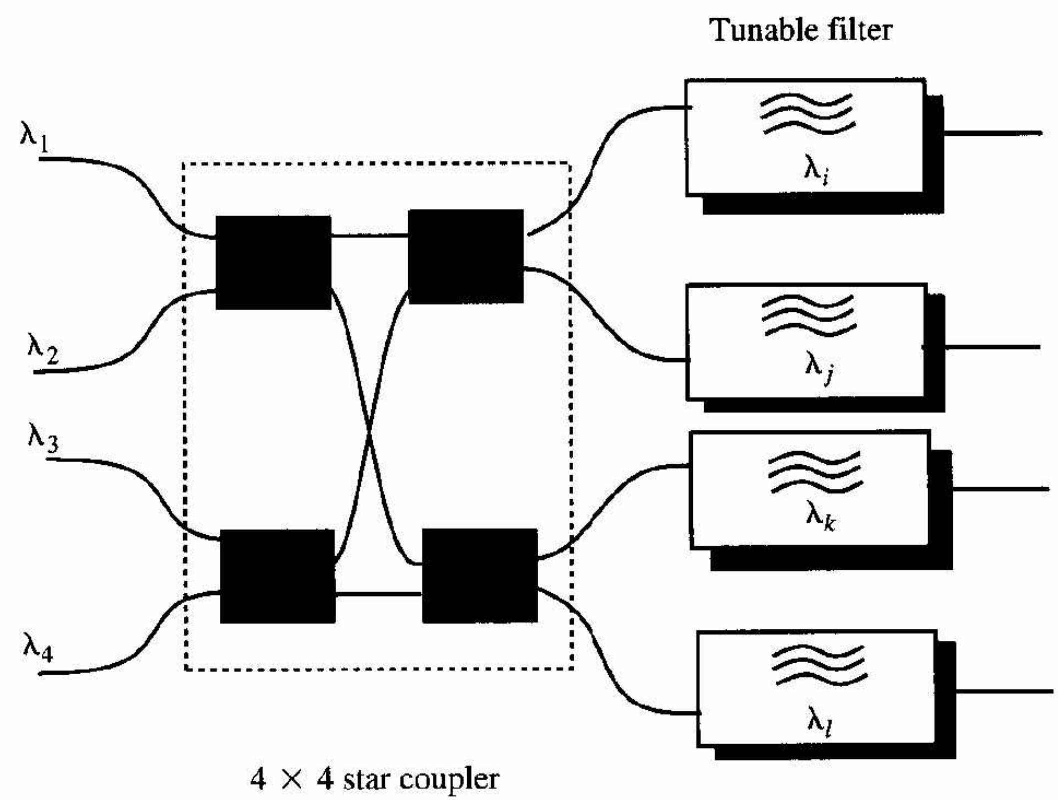


Figure 2.10 Illustration of a 4 × 4 WDM photonic switch.

Switching in Optical Networks

- Both circuit switching and packet switching have been used in optical communication networks
- By predefining the switching configuration in circuit switching, the switching control can be simplified and does not need to be processed in real time
- Therefore, circuit switching is preferable in optical communications where transmission speeds are high

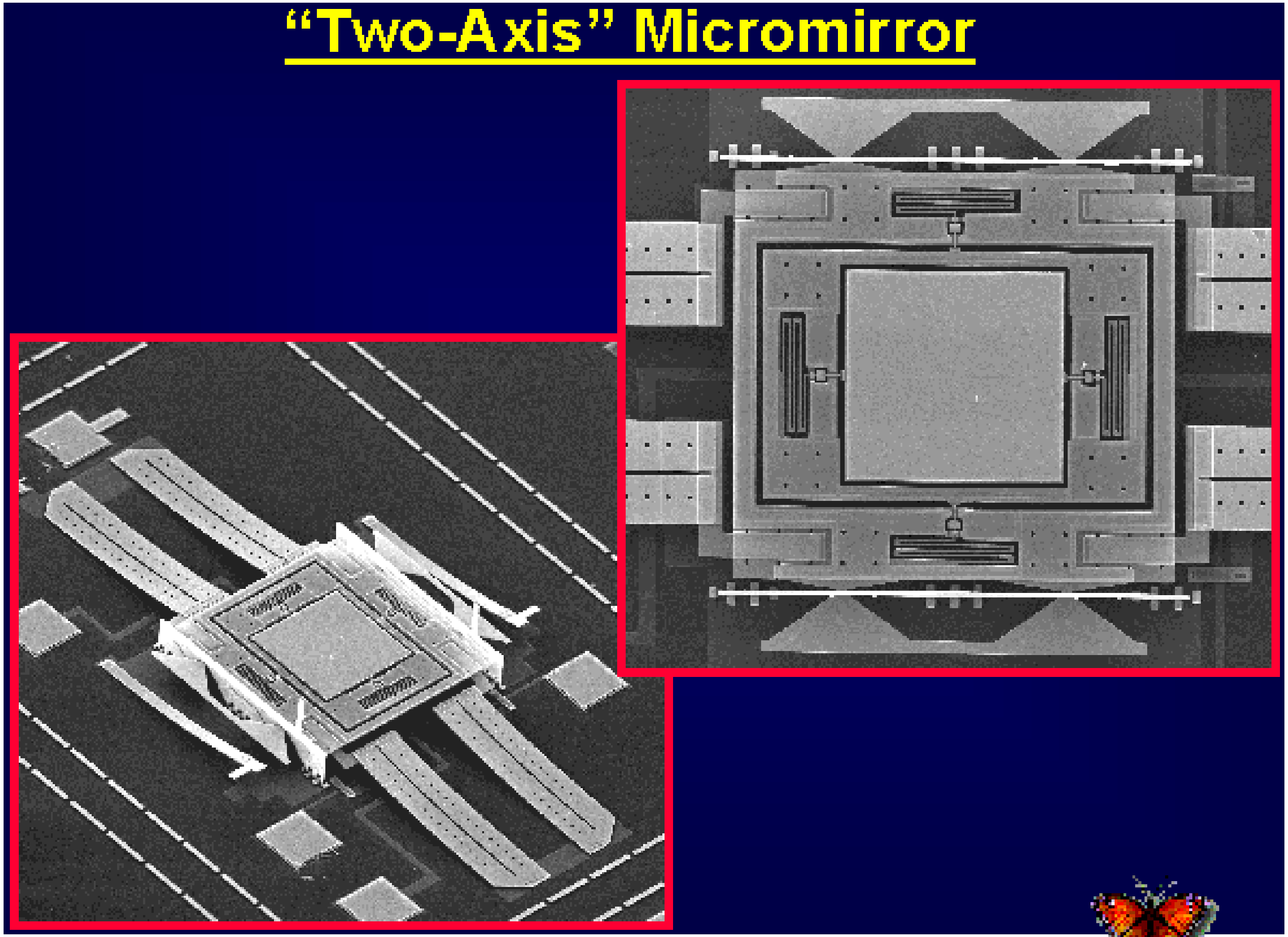
Switching in Optical Networks

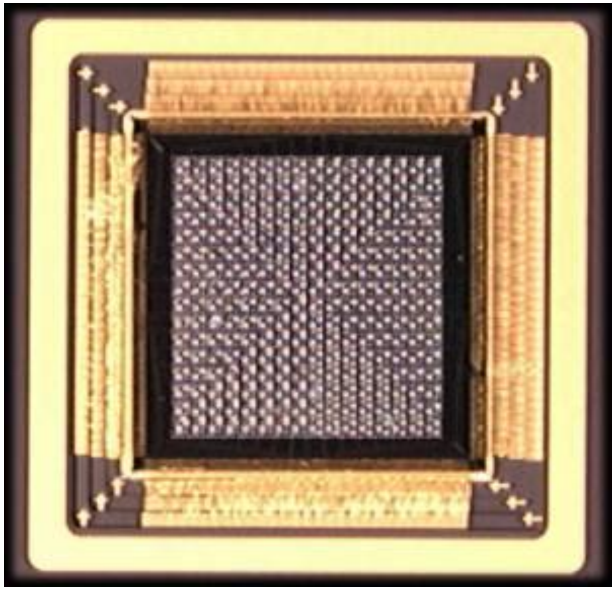
- In packet switching, as transmission speeds become higher and higher, packet duration becomes shorter and shorter
- As a result, the speed requirement of changing the switching configuration also becomes tougher
- For example, when the switch is large, the switching speed will be limited by the internal bus capacitance

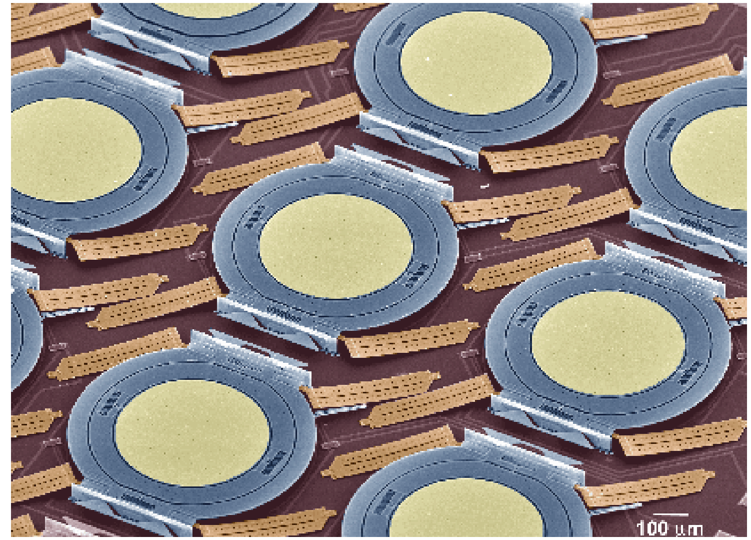
Switching in Optical Networks

- When photonic switching is considered, packet buffering in switching poses another problem
- Because photons cannot be stored as electrons can, as photons have no rest mass, it is difficult to buffer photons other than by introducing delay lines
- As a result, many packet switching designs that employ buffering to reduce blocking probability cannot be easily employed in photonic switching

Optical Switching Using MEMS Technology

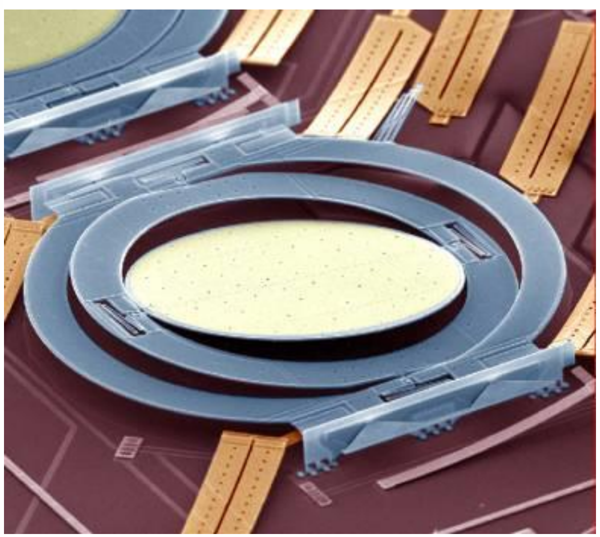


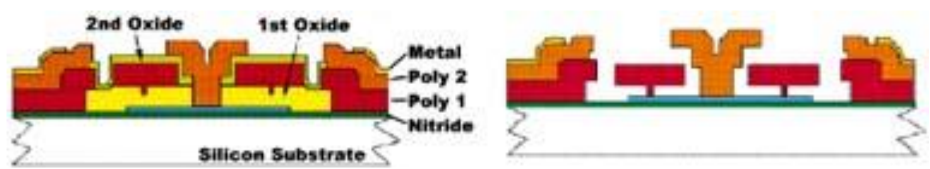




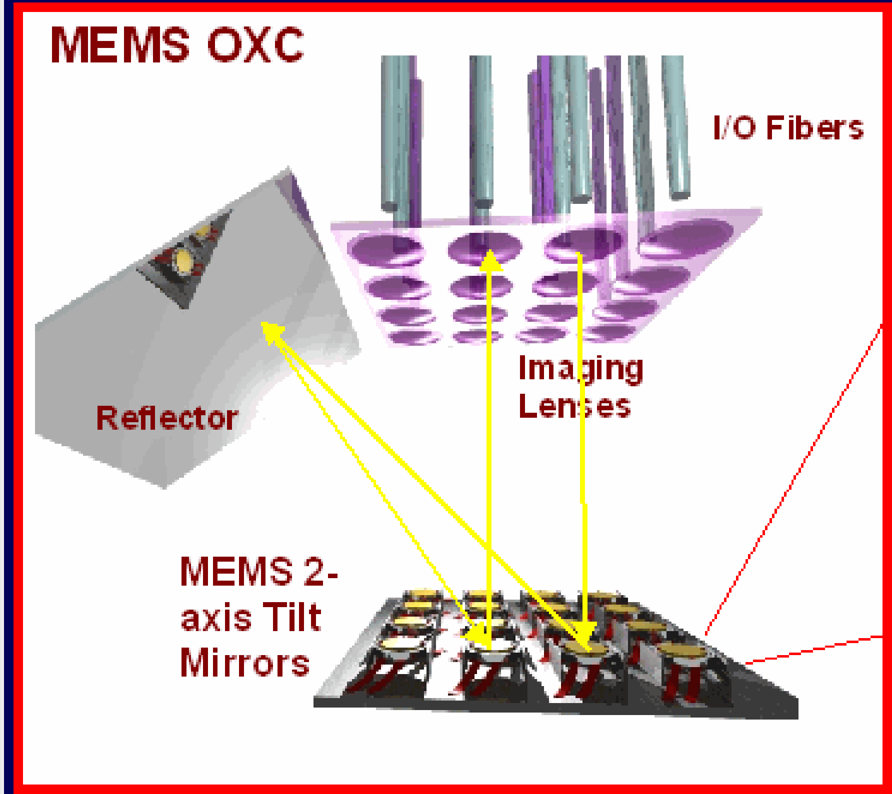
Packaged Microstar Mirror

Array with 256 mirrors





Lucent MEMS OXC



MEMS DEVICE:

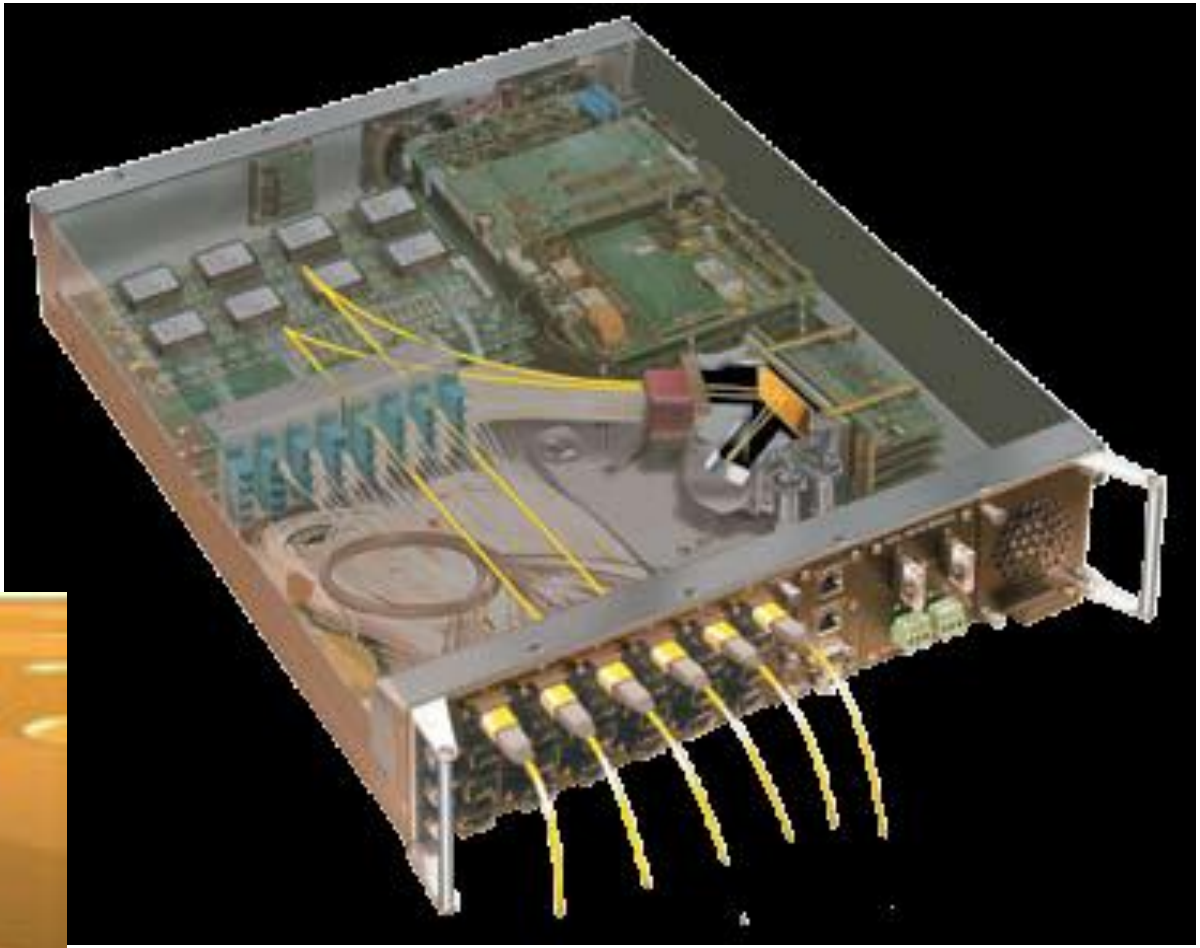
- 2-axis, angular range of > ±6°
- continuous, controlled tilt
- directly scalable to 256 mirrors (1024 in the long term)
- simple technology for rapid development / prototyping
- manufacturable

Cross Connect Realisation

MEMS Optical Switching

- Data Centers are key to the New Optical Internet. Connected by high speed fiber-optic links to the rest of the Internet, they provide key resources and services.
- Managing the distribution of these external optical links to the Data Center server farms is an increasing problem for Data Center managers.
- Rapid growth in both the number and speeds of these links, combined with the need for increased reliability and flexibility, must be handled while reducing operational costs.

Glimmerglass Intelligent Optical Switch



Glimmerglass Intelligent Optical Switch

System 500
32x32 - 190x190

Glimmerglass Intelligent Optical Switch

Transparent, Non-Blocking Fiber Connections

- • Connects input fibers to output fibers (in x out)
- • Single mode fiber, wideband (1270 nm - 1630 nm)
- • Connects fibers transparently, using MEMS micro-mirrors
- • All traffic data rates
  - Up to OC-768, 10GE and DWDM
- • Transparently accepts all signal formats
  - SONET/SDH, Ethernet, digital, or analog
- • Sizes from 24x24 to 190x190 fibers

Glimmerglass Intelligent Optical Switch

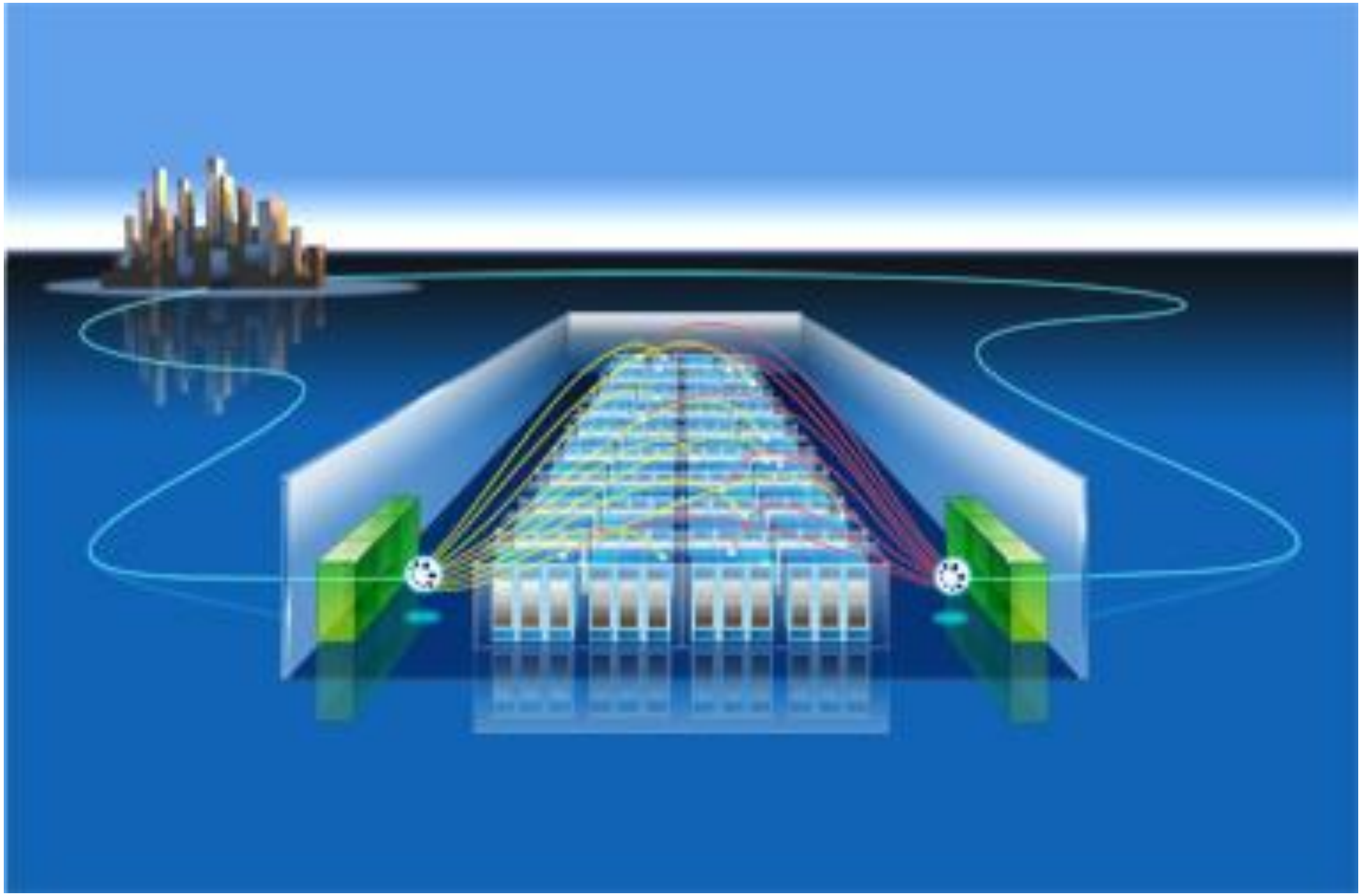
Available Features

- • Optical power monitoring on all fibers in real-time
- • Alarm triggers and configurable optical power thresholds
- • Automatic protection switching
- • Connect point to multipoint via Photonic Multicasting
- • Control optical power with Variable Optical Attenuation
- • Partition switch with Virtual Private Switching
- • Multi-switch management from single console

MEMS Optical Switching

- MEMS optical switches provide a full non-blocking, transparent crossconnect.
- In milliseconds a lightpath can be created between any fiber input and output.
- The distribution of external feeds to server farms can be rapidly and remotely reprovisioned with a few clicks of a mouse using the Glimmerglass ClickFlow GUI interface or with a few TL1 commands.
- Since the lightpaths are fully transparent, the newly created lightpath will transport any data format and speed.

Data Centre



Data Centre

- Glimmerglass Intelligent Optical Switches have the highest fiber density in the industry.
- Up to 190 fibers (95 x 95) are supported in just two rack units (3.5" or 8.9cm) and up to 380 fibers (190 x 190) in 4 rack units.
- Weighing only 20 to 38 pounds (9 to 17kg), power consumption ranges from 35 to 80 watts and requires no special cooling

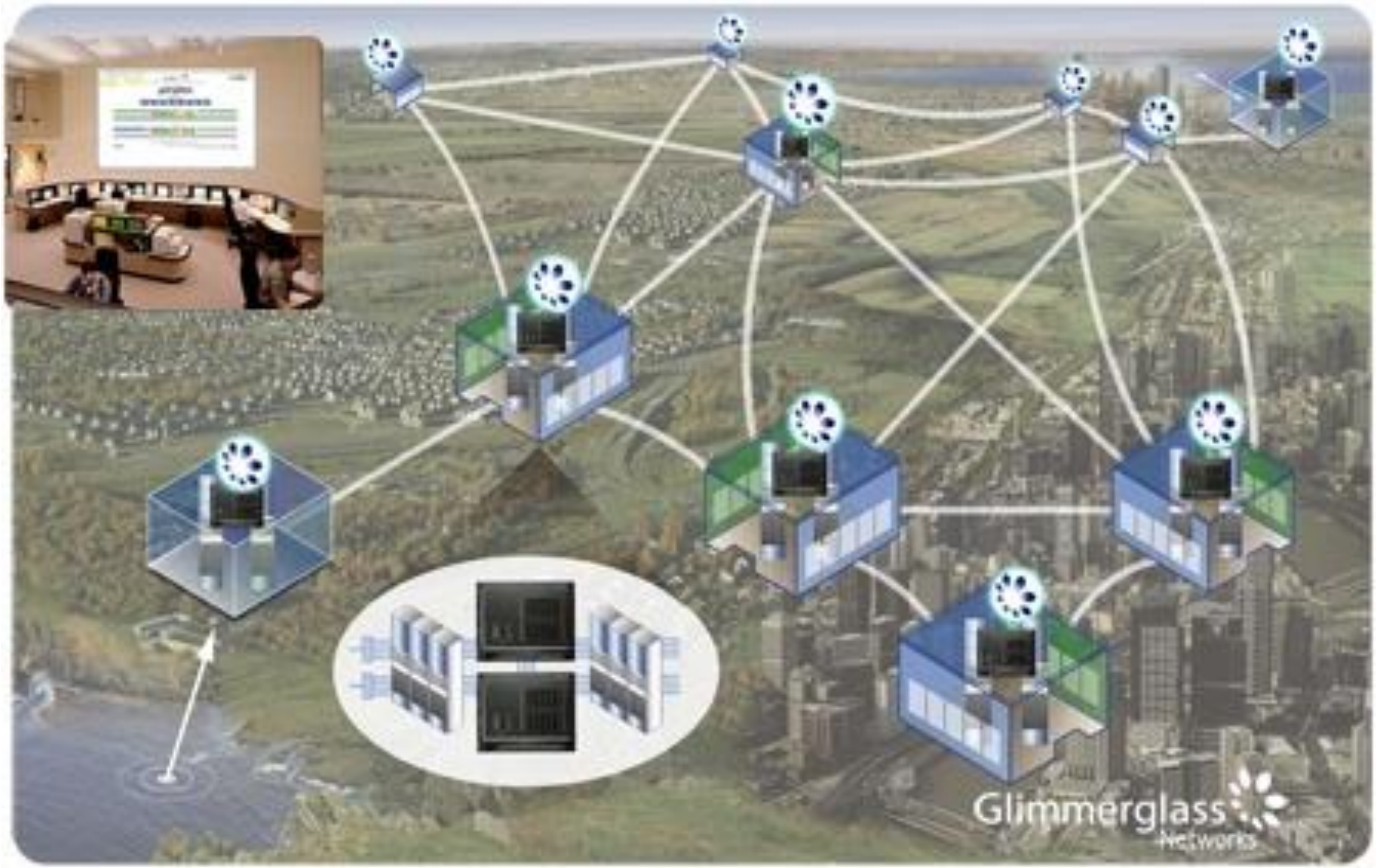
Data Centre

- Intelligent Optical Switches provide fully transparent crossconnects. Once installed, the Data Center is ready for any future data rate or format.
- No changes are required to migrate from GE to 10GE to 100GE or even 40G SONET/SDH. Upgrade the endpoints, not the switching fabric.
- As non-blocking crossconnects, solutions facilitate the introduction of new server equipment and future migrations to new architectures

Telecomms Central Office

- In the New Optical Internet, Telecomms Central Offices are becoming overloaded with fiber.
- Connected by high speed fiber-optic links to the rest of the Internet, they are the major aggregation and disaggregation points and, with the rapid growth of FTTx, the customer links are also increasingly fiber-based.

Telecomms Central Office



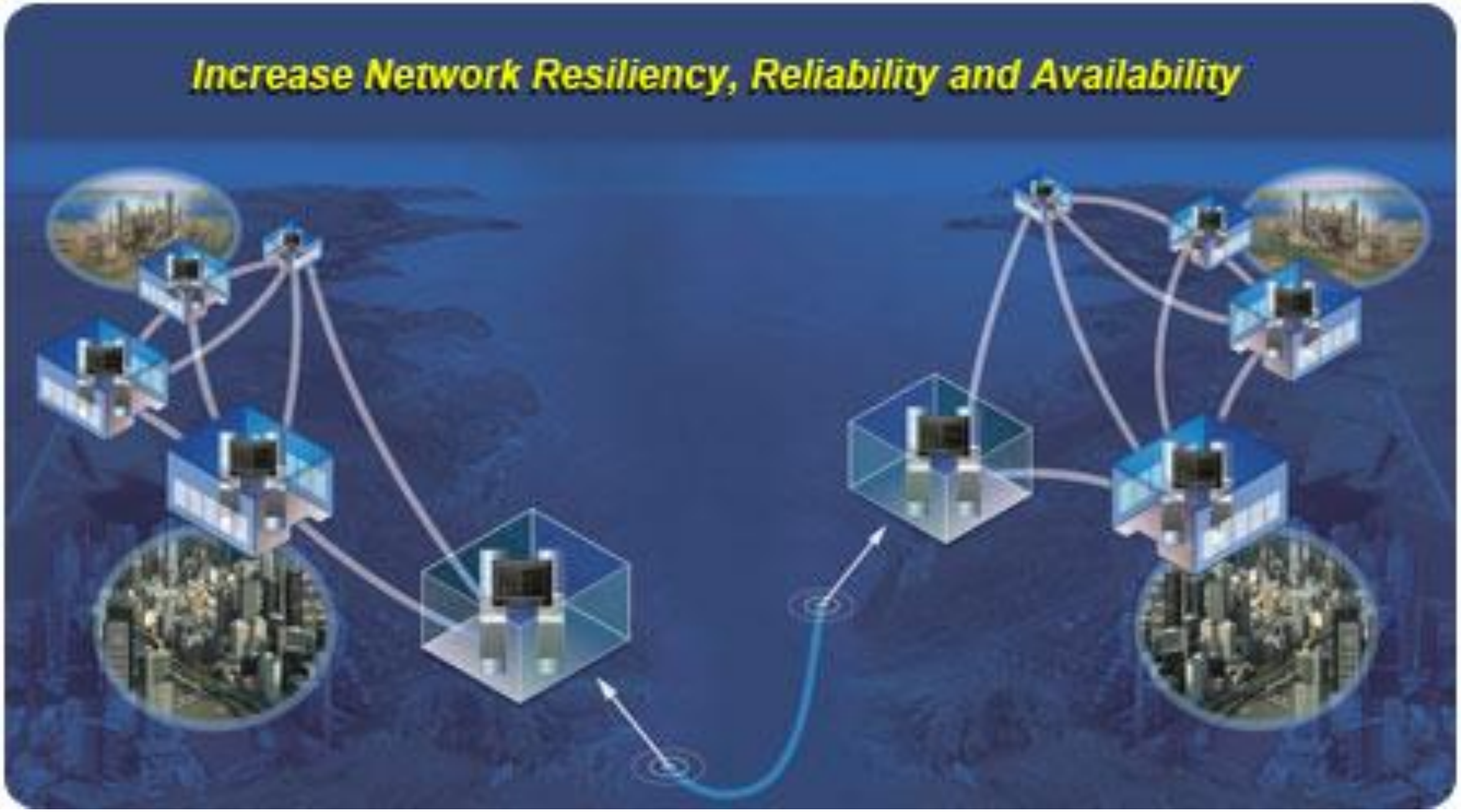
Undersea fiber-optic cables

- Undersea fiber-optic cables provide the vast majority of the intercontinental bandwidth of the Internet.
- Remotely Creating, Monitoring and Protecting the lightpaths on these fibers is increasingly important to the New Optical Internet.
- With the rapid growth in the amount of traffic carried on undersea cables, the outages seen in the past caused by cable breaks and equipment failures are no longer acceptable.
- Glimmerglass Intelligent Optical Switching solutions greatly improve availability and reduce capital and operating costs by facilitating flexible “Lights Out” landing sites.

Failure Protection

- In the event that Glimmerglass power monitoring detects a failed wavelength transponder, traffic can be automatically routed through a standby transponder. This N to 1 protection results in significant savings in sparing and permits repairs to be performed on a scheduled instead of emergency basis.
- With the ability to rapidly transfer massive data streams from one set of lightpaths to another, switches are also the ideal solution implementing full mesh cable protection.

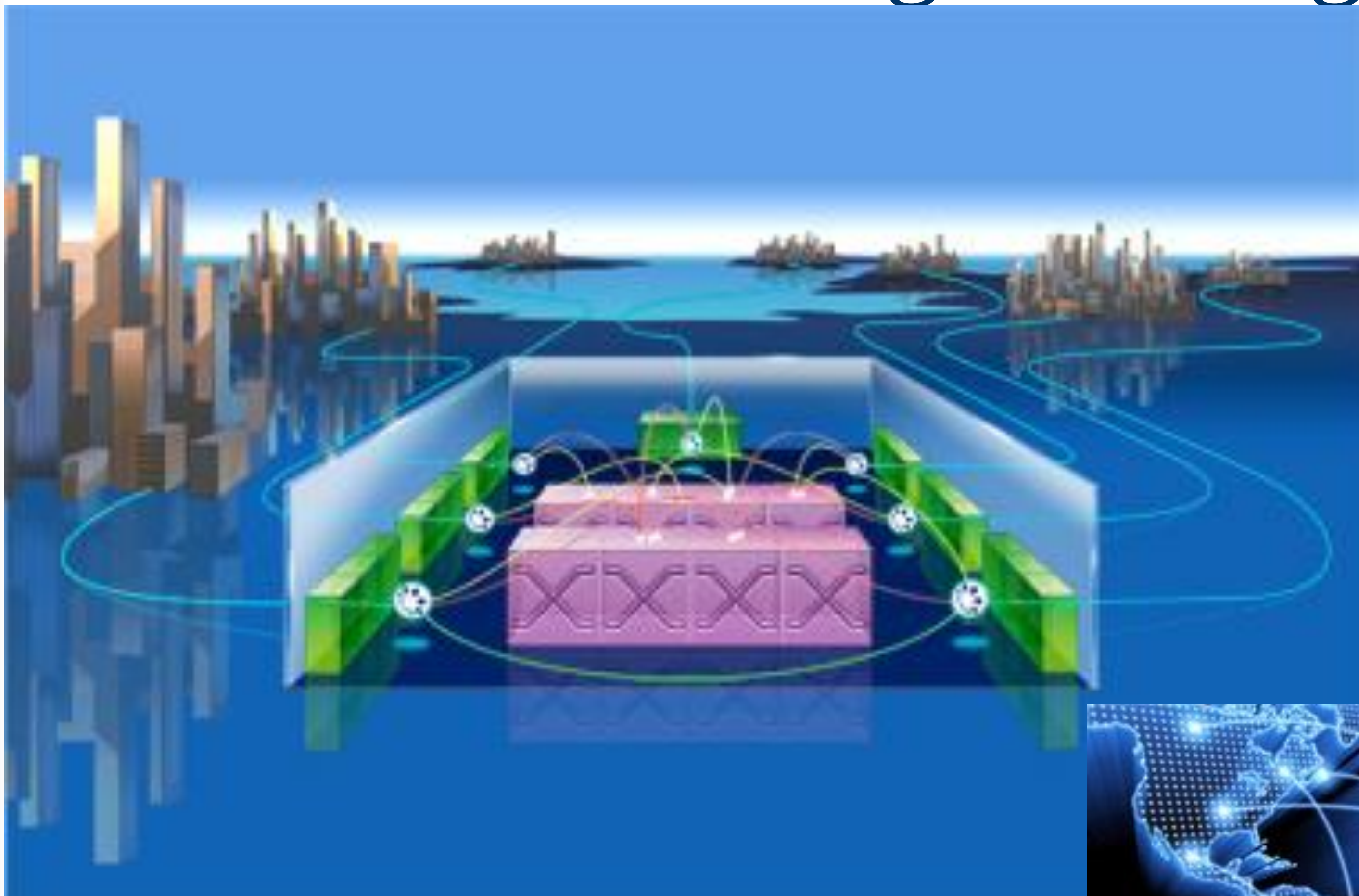
Undersea fiber-optic cables



Internet Peering Exchange

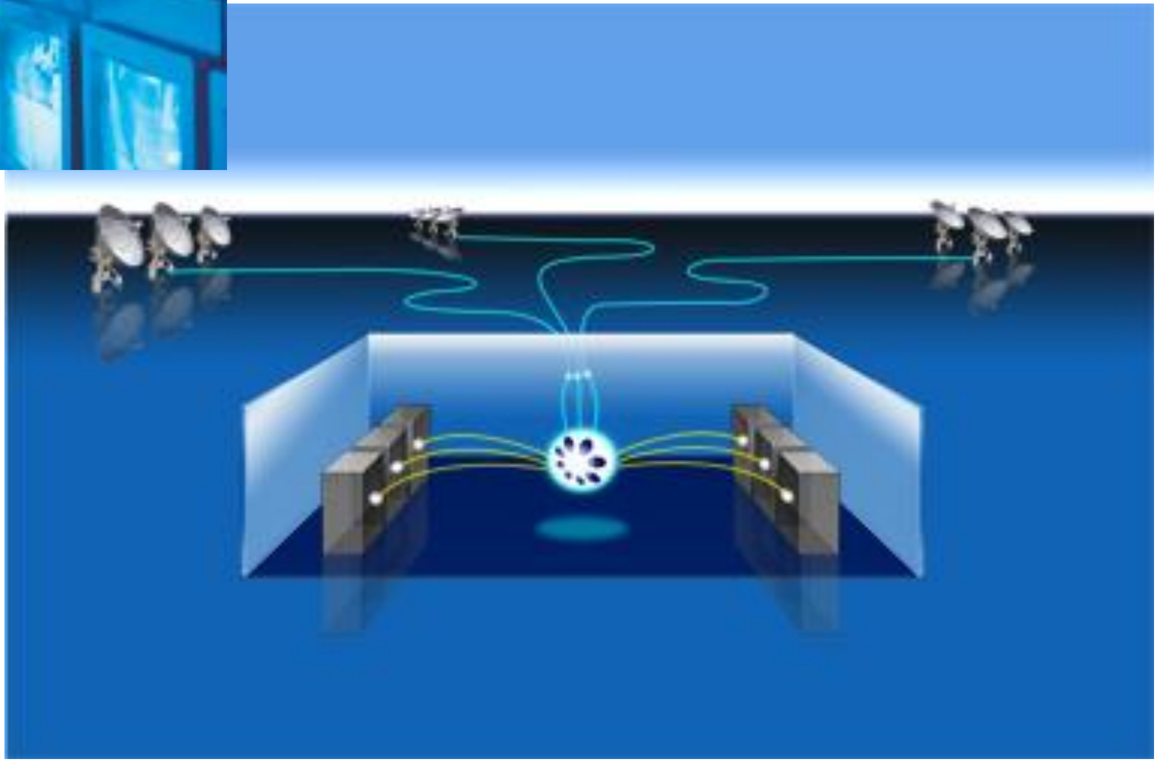
- An Internet Exchange is a meeting point for independent Internet Service Providers (ISPs) enabling them to exchange Internet traffic with each other, nationally and internationally.
- This exchange of traffic is known as “peering.” Since without peering, the Internet is nothing, network reliability at Internet Exchanges is of extreme importance.
- In addition, rapid growth of the Internet has resulted in Internet Exchanges seeing traffic double every year. This places a severe strain on both network architecture and planning.
- Intelligent Optical Switching solutions greatly improve network reliability and provide the flexibility to handle high growth.

Internet Peering Exchange

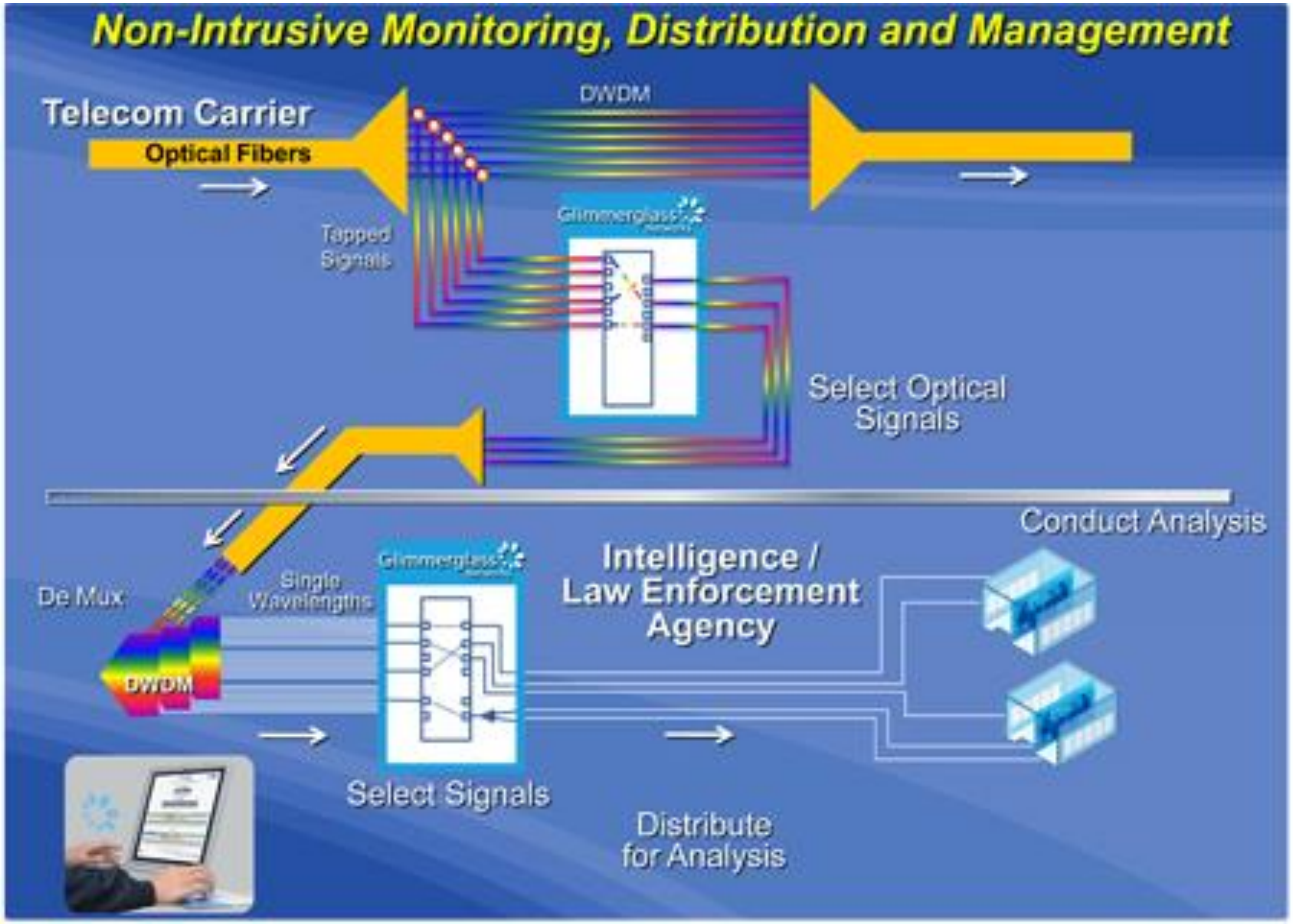


Government Signal Monitoring

Government Signal Monitoring



Government Signal Monitoring



Topology

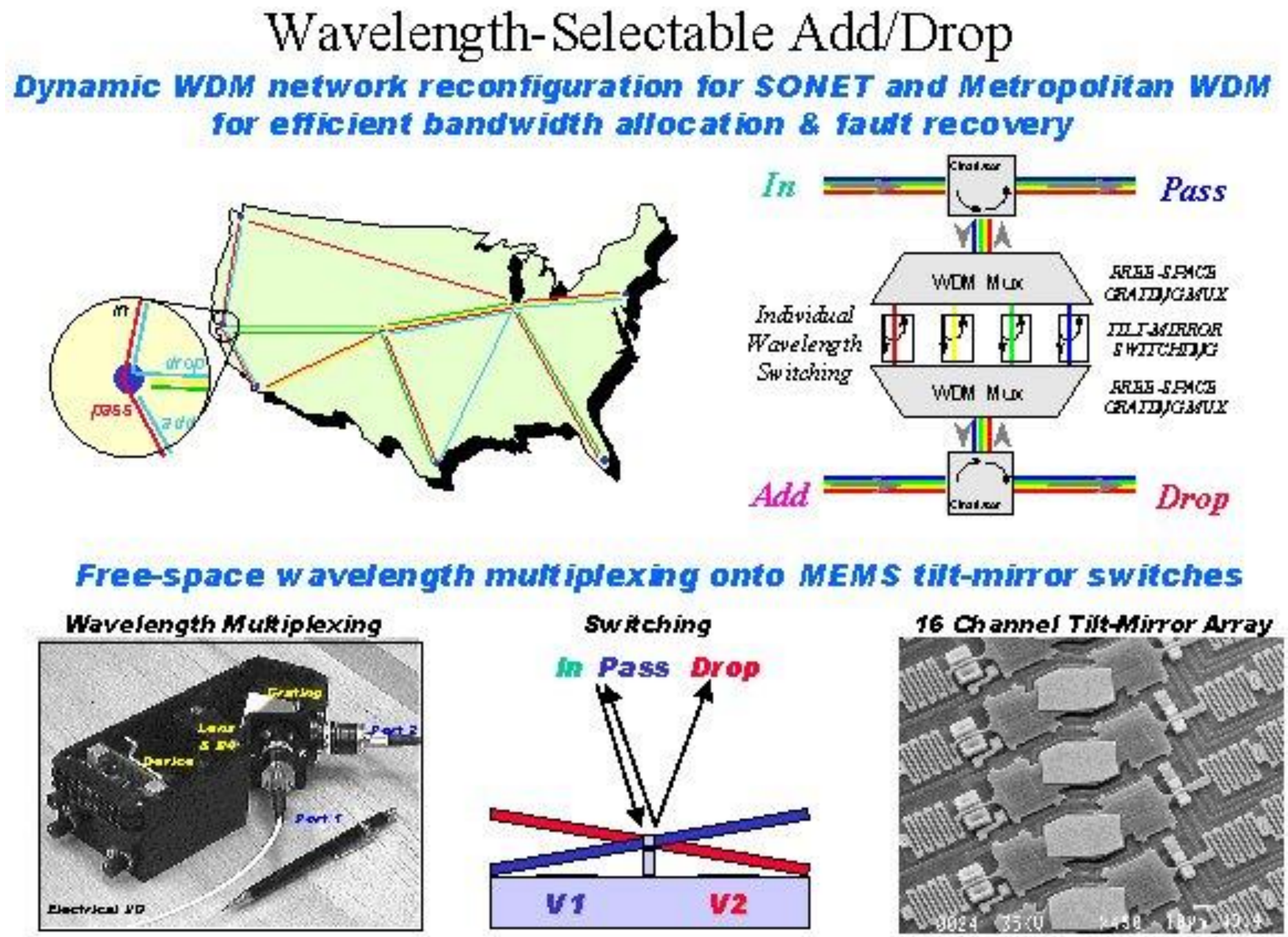
- There are three basic types of topology:
  - Ring
  - Star
  - Bus
  - Mesh
- Combinations of these three basic topologies can be assembled into more complex communication networks

Synchronous Optic Network (SONET)

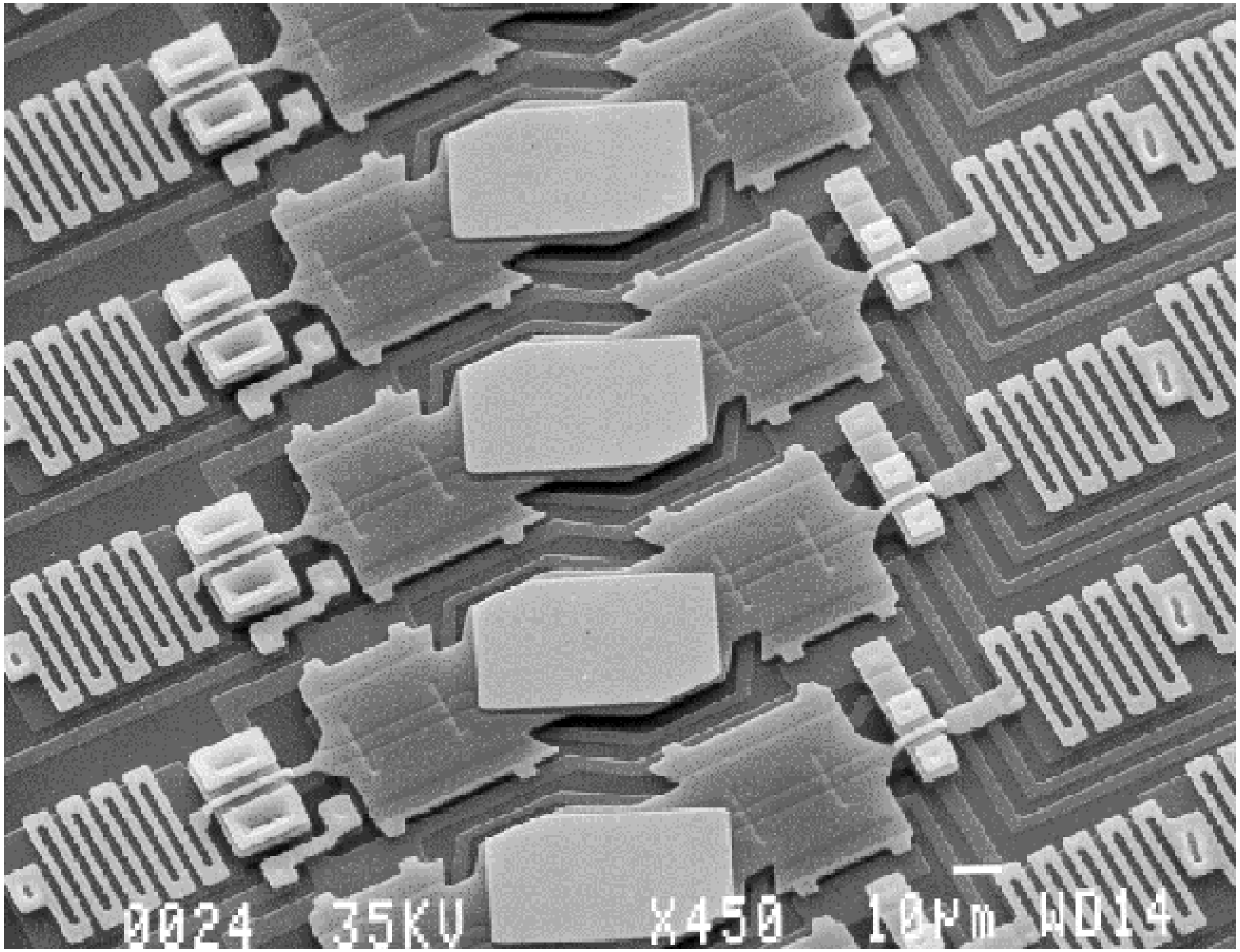
- SONET is a standardised worldwide lightwave transmission system. It is a TDM system similar to the T-carrier in digital telephony
- To overcome the high-speed multiplexing problem in TDM, SONET uses an innovative frequency justification technique called **pointer processing**
- Once all low-speed signals are frequency justified with respect to the same clock, they can be multiplexed to a high speed signal by straightforward byte interleaving
- This minimises the high speed processing requirement
- In exchange for the simpler multiplexing and demultiplexing, SONET uses more overhead bits than the T-carrier

High Speed Applications

- Lightwave technology is expensive if the ample bandwidth is not well utilised
- For example, there is no reason to replace Ethernet by fibre optics in a small office enviroment
- Lightwave technology requires high speed applications such as:
- Medical imaging, security and surveillance systems, video conferencing and multimedia, CAD/CAM and design, community antenna TV systems can support 40-75 analogue TV channels, with SCM transmission 150 channel transmissions have been reported
- High performance computing achieved by integrating several remotely separated computers into a supercomputer


Wavelength-Selectable Add/Drop
Dynamic WDM network reconfiguration for SONET and Metropolitan WDM
for efficient bandwidth allocation & fault recovery
In
Pass
in
drop
pass
add
WDM Mux
WDM Mux
Individual
Wavelength
Switching
TILT-MIRROR
SWITCHING
Add
Drop
Free-space wavelength multiplexing onto MEMS tilt-mirror switches
Wavelength Multiplexing
Grating
Port 2
Port 1
Electrical I/O
Switching
In
Pass
Drop
V1
V2
16 Channel Tilt-Mirror Array

Add/Drop Multiplexer



End